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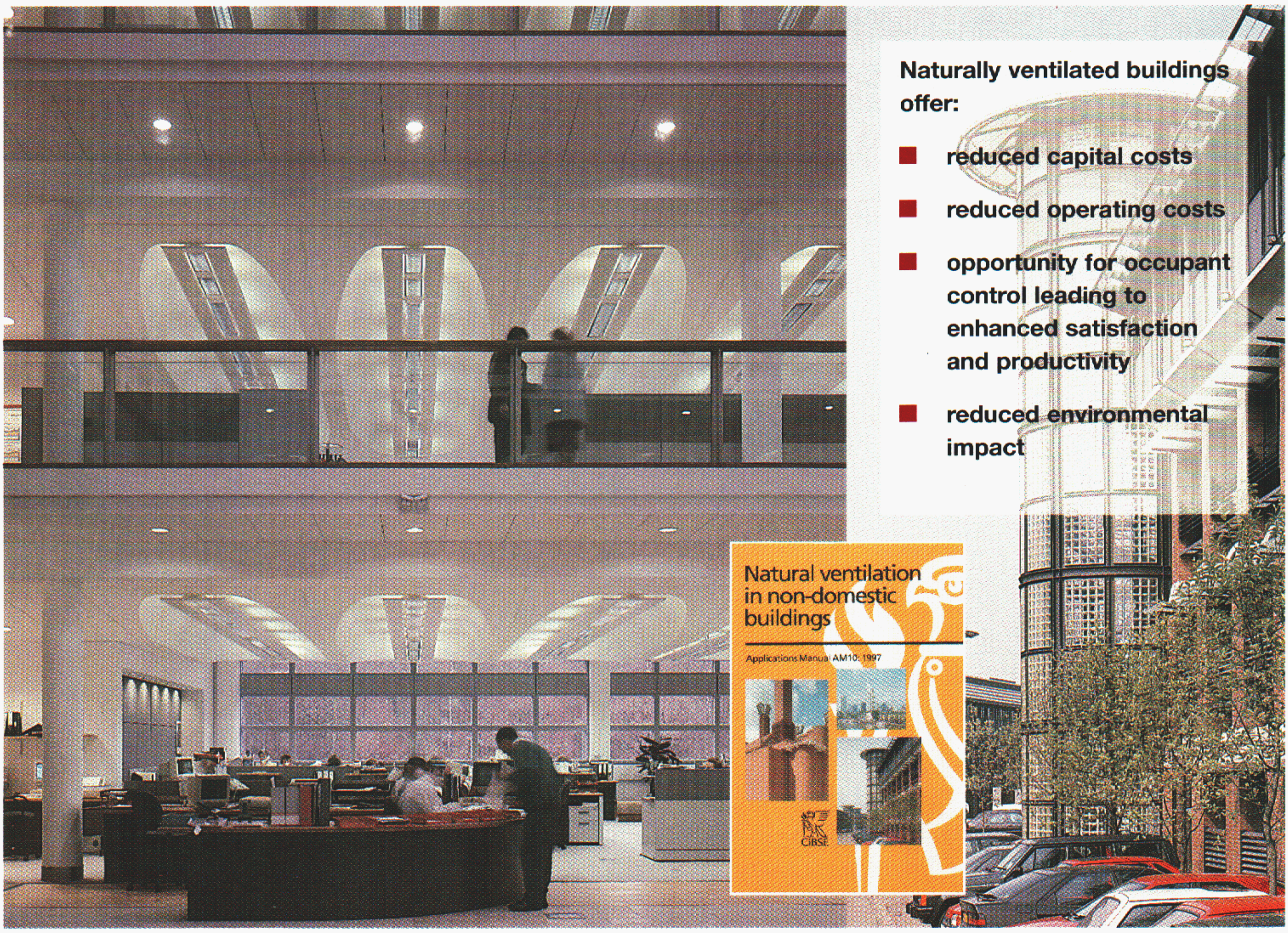
GOOD PRACTICE GUIDE 237

Natural ventilation in non-domestic buildings

– a guide for designers, developers and owners



Naturally ventilated buildings offer:

- reduced capital costs
- reduced operating costs
- opportunity for occupant control leading to enhanced satisfaction and productivity
- reduced environmental impact

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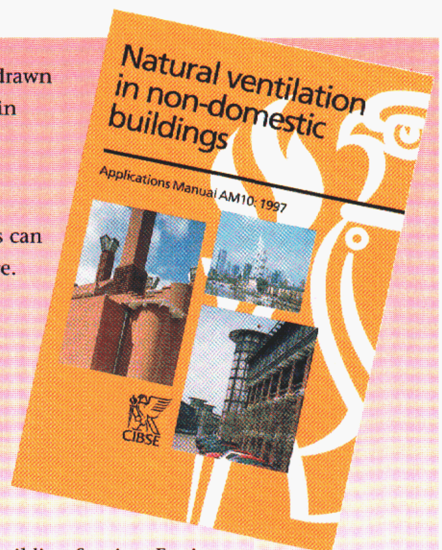
CONTENTS

Much of the material in this Good Practice Guide has been drawn from the CIBSE Applications Manual on natural ventilation in non-domestic buildings. The manual is intended to help all members of the design team, including the client.



As the manual proceeds, the level of detail increases. Readers can take their study of the subject to whichever level they require. There are six main sections:

- natural ventilation as a design strategy
- developing the brief
- selecting a strategy
- ventilation components
- design calculations
- case studies.

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The manual is available from: The Chartered Institution of Building Services Engineers, 222 Balham High Road, London SW12 9BS.

INTRODUCTION

Natural ventilation is becoming an increasingly important design strategy for many non-domestic buildings. With careful design, such buildings can be cheaper both to construct and to operate than more heavily serviced equivalents. Many occupants express a preference for opening windows and natural light, both of which are features of well-designed naturally ventilated buildings. Low construction and running costs and a high level of occupant satisfaction are key requirements for efficient buildings.

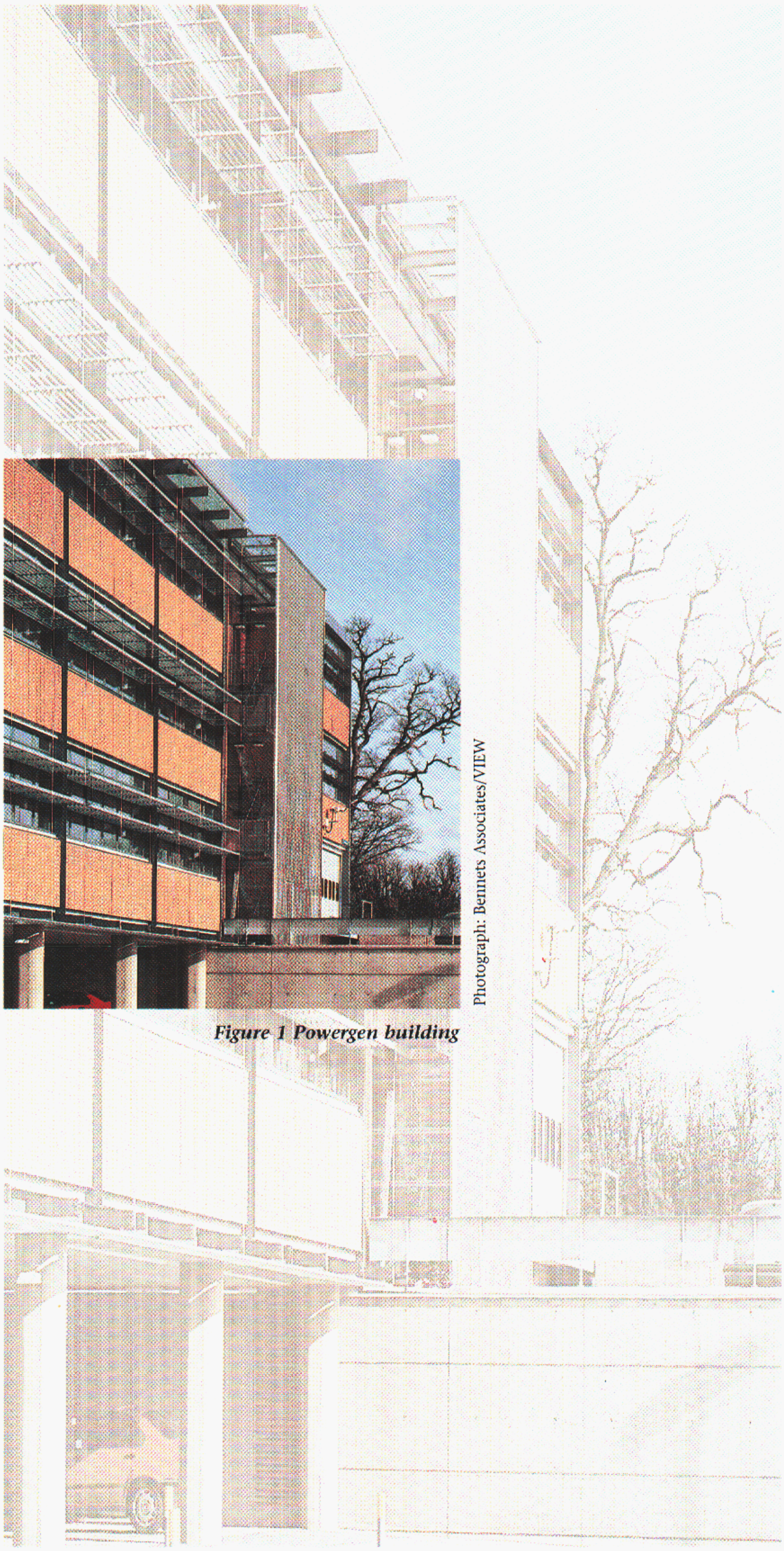
If natural ventilation is to work effectively, it must be planned from the earliest stages of design. This requires a team-based approach, with all the disciplines working with the client to achieve the desired objective.

This Guide first summarises the features and benefits of natural ventilation, allowing it to be compared with other strategies including mechanical ventilation and air-conditioning. It then considers natural ventilation in the context of the commercial issues that are at the heart of building procurement. Finally, it illustrates the features of naturally ventilated buildings by reviewing design issues from a selection of case studies.

This Guide may be regarded as a primer for the CIBSE Applications Manual, 'Natural ventilation in non-domestic buildings'[1], which describes in much more detail how to decide if natural ventilation is appropriate, and if so, how to design and implement a successful natural ventilation strategy.

WHO SHOULD READ THIS GUIDE?

- **Designers:** to understand the key features of naturally ventilated buildings and how to achieve successful designs.
- **Developers/owners:** to understand how to reduce the life cycle costs of the building, and identify the key briefing issues that affect performance.
- **Users:** to understand how improved user control enhances occupant satisfaction and improves productivity.



Photograph: Bennets Associates/VIEW

Figure 1 Powergen building

THE BENEFITS

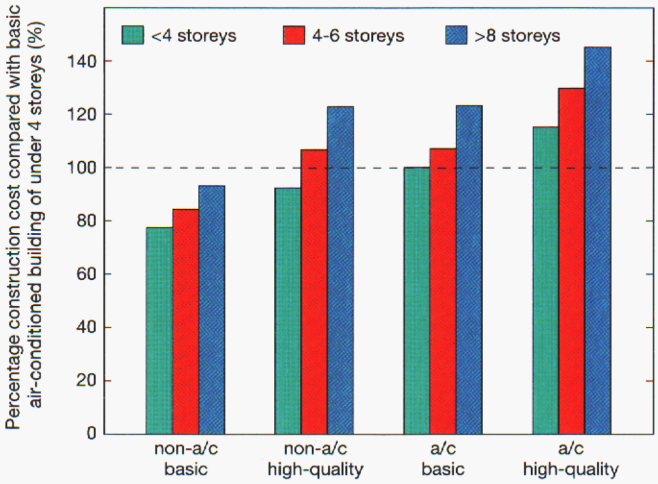


Figure 2 Relative construction costs (CIBSE Applications Manual 10, p6)

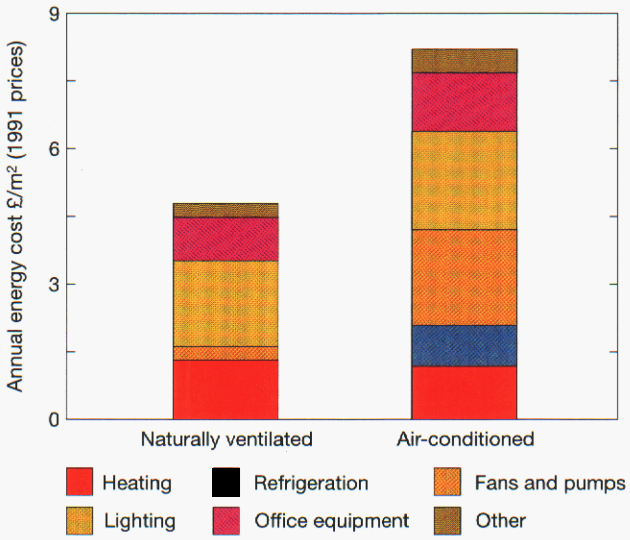


Figure 3 Relative energy costs

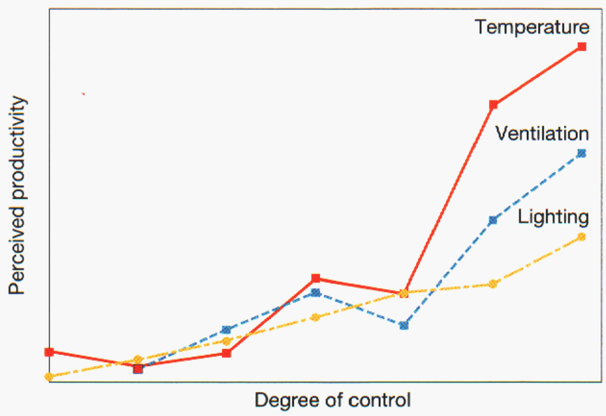


Figure 4 Perceived productivity as a function of the user's degree of control (CIBSE Applications Manual 10, p20)

Lower capital costs

Naturally ventilated buildings are cheaper to construct than equivalent mechanically ventilated buildings (see figure 2). A significant reduction in the cost of the engineering services will more than compensate for some extra costs in envelope improvements, such as external shading and openable windows. As a rule of thumb, naturally ventilated buildings cost about 10%-15% less to construct than air-conditioned equivalents[2]. Smaller plant may also require less plant room space (but see 'Flexibility and adaptability', opposite).

Lower operating costs

Information collected by those in the profession shows that well-designed, naturally ventilated buildings are usually cheaper to run than air-conditioned buildings (see figure 3), providing openings are well sealed to control infiltration losses in winter. Equally, well-designed mechanically ventilated buildings with low specific fan power and high-efficiency heat recovery can also achieve very low annual energy consumption. Maintenance costs are also lower in naturally ventilated buildings due to the reduced scale and complexity of the engineering systems.

Data from Jones Lang Wootton[3] suggest that service charges in a naturally ventilated building are less than half those in a similar air-conditioned building.

Occupant preferences

Recent occupant surveys[4] have revealed that most people prefer a work space that is naturally lit and ventilated providing that comfortable temperatures can be maintained (see 'Comfort standards', page 7).

Occupant productivity

Studies[5] indicate that staff feel productivity is improved if they have individual control over their environment (see figure 4). Increasing the local ventilation rate by opening a window is one example of such individual control; the ability to operate blinds is another. By using these controls, thermal conditions, ventilation rate and glare can be changed rapidly, thereby enhancing the occupant's perception of individual control.

THE BENEFITS

Reduced environmental impact

Naturally ventilated buildings have a smaller environmental impact through reduced energy demand (particularly electrical). This reduces emissions of carbon dioxide (CO_2) and other combustion products that contribute to the risk of global warming. Buildings constructed according to environmentally sensitive principles are good long-term investments, because environmental controls and legislation are likely to increase in the future.

Photograph: Feilden Clegg Architects

Figure 5 John Cabot City Technical College

Robustness

Naturally ventilated buildings rely on the passive elements of the building structure to provide the primary environmental control. This approach significantly reduces the number of electrical and mechanical components installed in the building, which are potential sources of system failure or malfunction. The building dampens the diurnal and seasonal swings in temperature, providing an environment that is linked to the prevailing weather conditions, and so conforms to occupant expectations of comfort level.

Flexibility and adaptability

The ability to change the use or layout of a building is an important design consideration. Natural ventilation enables the building to meet the needs of many types of user. By sensible planning at the design stage, it is possible to provide in-built layout flexibility so that the building can, if required, cope with more demanding use in the future. Identification of areas that can be converted to plant room space for air-handling plant and chillers (if required), and breakout floor zones to provide service risers will allow virtually any level of servicing requirement to be provided as a retro-fit.

Photograph: Dennis Gilbert/VIEW

Figure 6 Inland Revenue Building

The advantage of this approach is that the extra servicing needs to be provided only when it is required, and to those parts of the building that justify it. This combines flexibility in use with the potential to manage cash flow so that investment is made as and when the needs of tenants are known. Studies[6] have shown that buildings that were let before being fitted out usually scored best in terms of both occupant comfort and energy efficiency.

THE BENEFITS

FEATURES	BENEFITS	COMMENTS
The building acts as the primary climate modifier	Simpler and more manageable environmental systems	Greater design effort is required to ensure satisfactory operation
Reduced reliance on mechanical plant (eg air-conditioning)	Lower construction and maintenance costs	Upper limit of 30 W/m^2-40 W/m^2 on total coincident heat gains. Greater care is needed to avoid loss of flexibility in partitioning and layout
Potential for personal control of the environment using openable windows	Increased user satisfaction and productivity	Available only for occupants at the perimeter. Not effective for deep plan buildings
Less electrical energy used for ventilation and cooling, with the possible elimination of refrigeration	Reduced operating costs and a more environmentally conscious approach	Greater variability in internal conditions. High thermal capacity and cooling by night ventilation can maintain comfortable temperatures

The features and benefits of natural ventilation

TYPICAL FEATURES OF NATURALLY VENTILATED BUILDINGS

Buildings that deliver the benefits described above have a number of common features.

- Narrow plan width – the distance between the façades (external to external, or external to atrium or courtyard) is usually limited to about 15 m.
- Floor-to-ceiling heights of approximately 3.0 m – permits good daylight penetration and allows stratification of the air to improve both thermal comfort and indoor air quality at the occupied level.
- Good solar control – to avoid excessive solar heat gains. This can be achieved by sensible choice of orientation, glazing ratio and shading (both fixed and adjustable).
- Well-controlled internal gains – lights and equipment are efficient and switched off when not required.
- High thermal capacity – using the mass of the building to smooth out fluctuations in internal temperature. This usually requires exposed or semi-exposed ceilings. (For further information see New Practice Final Report (NPFR 106) 'The Elizabeth Fry Building, University of East Anglia – feedback for designers and clients'.)
- Well-designed windows with easily adjustable ventilation openings.

COMMERCIAL CONSIDERATIONS

Floor area

Naturally ventilated buildings are relatively narrow in plan, which tends to reduce the ratio of the net to gross area. The available space is of high quality because occupants prefer natural light and views of the outside world. The linear form that is common in naturally ventilated buildings enhances communication within and between work groups. The smaller plant room space required by naturally ventilated buildings can offset the reduced space efficiency (unless contingency space is reserved for retro-fit services).

Floor-to-ceiling height

Increased floor-to-ceiling heights increase the efficiency of both natural ventilation and daylighting. This need not be at the expense of overall building height, because the false ceiling is often dispensed with in order to expose the slab, which will increase the effective thermal capacity of the structure. The increased room height also provides contingency space to allow the building to be subsequently fitted out with a mechanical system, if required, while still retaining good floor-to-ceiling heights. Attractive ceilings with integrated lighting can be achieved.

Small power loads

Traditionally, the cooling requirements of small power loads have been significantly overestimated (for further information see General Information Report 48 (GIR 48) 'Passive refurbishment at the Open University – achieving staff comfort through improved natural ventilation'). Only in exceptional circumstances would the average gain from IT equipment exceed 20 W/m^2[7]. (It should be noted that this figure is for assessing cooling provision; a higher figure should be used when assessing the provision for electrical power.) Specifying unrealistically high small power loads may result in eliminating natural ventilation as a design option and then installing unnecessary or oversized cooling equipment. This wastes capital and results in inefficient plant which is difficult to control.

By specifying well-controlled equipment (eg monitors that revert to standby mode when not in use), further reductions in cooling load can be achieved. Realistic estimates of the cooling load due to IT, combined with good lighting design and good solar shading, mean that natural ventilation is a cost-effective cooling strategy.

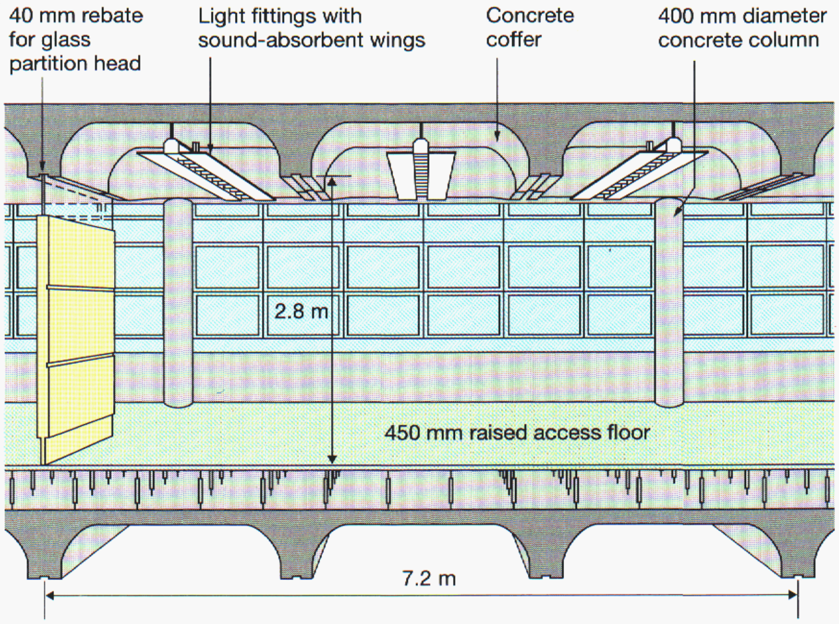


Figure 7 Powergen building – ceiling detail based on a British Cement Association Project Profile[9]

Comfort standards

Institutional comfort standards have been based on achieving a specified air temperature. In summer, the same level of comfort can be achieved at higher air temperatures if radiant temperatures are reduced and air movement is enhanced. Reduced radiant temperatures are achieved by using a high thermal capacity structure cooled by night-time ventilation. Increased local air movement can be provided through user control of opening windows. Comfort is further enhanced if occupants can adapt their clothing in warmer weather (no jackets, short sleeved shirts, etc). The performance specification for the Energy Efficient Office of the Future (EOF)[8] provides guidance on appropriate standards.

In winter, care has to be taken to avoid cold draughts. This can be overcome by specifying inlets which are easily controlled, well sealed when closed, and carefully positioned.

DESIGN STRATEGIES

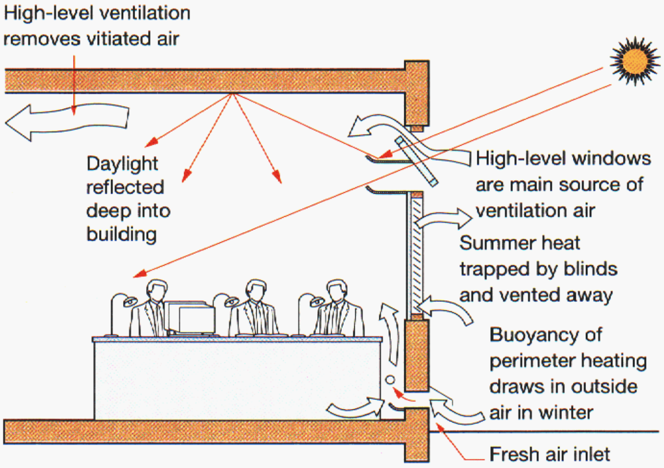


Figure 8 Anglia Polytechnic University façade detail (CIBSE Applications Manual 10, p66)

Urban/rural location

External noise and pollution are often cited as reasons for adopting mechanical systems. In city centres, natural ventilation is more difficult to achieve, though not impossible. By drawing the ventilation air from a courtyard or quiet side of the building, acceptable air quality can be achieved. Even if filtration and mechanical ventilation are essential, the principles of high thermal capacity and night ventilation can provide an effective low-energy cooling system, providing fan power loads are minimised through careful design.

DESIGN STRATEGIES

The first stage in the design process is to assess the viability of natural ventilation. The nature of the site or the way the building is to be used may well dictate that a mechanically ventilated or air-conditioned building is more appropriate.

The following sketches illustrate the principal mechanisms that drive natural ventilation. Achieving natural ventilation is only one aspect of successful design; daylight, glare control, heating, acoustics, fire safety and many other issues have to be integrated into an overall strategy. Examples of design for natural ventilation and the integration of some of the key design issues are described in the case studies on pages 12 and 13.

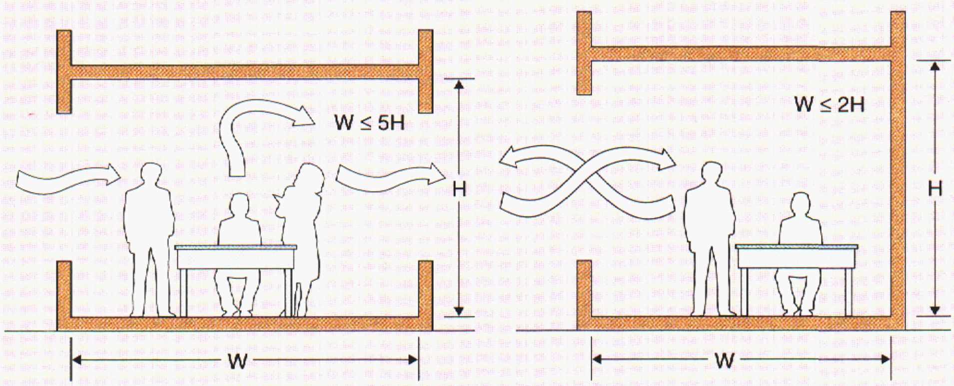


Figure 9 Wind-driven ventilation strategies (CIBSE Applications Manual 10, p27)

Wind-driven ventilation

Wind-induced pressure differences drive the air across the building. Effective cross-ventilation requires an unrestricted flow path; this means open-plan space or very low-pressure drop transfer grilles are required. Cellular space can be ventilated from one side only as a result of wind turbulence or local temperature differences. Orientation of the building with respect to the prevailing wind direction can enhance the potential for wind-driven ventilation.

DESIGN STRATEGIES

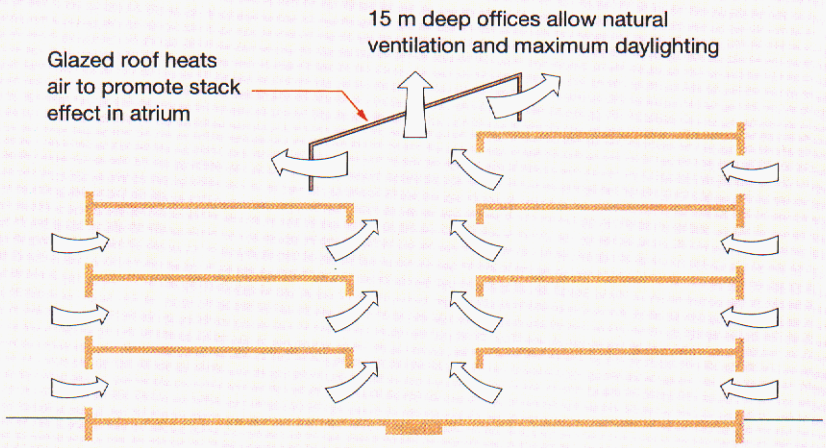


Figure 10 Stack-driven ventilation strategy (CIBSE Applications Manual 10, p30)

Stack-driven ventilation

The density difference between warm air inside the building and cooler air outside creates a pressure difference. This drives air into the building at low level, exhausting it at high level. The size of ventilation openings must also vary with height to achieve equal flow rates to account for the variation in pressure difference with height. Because exhausts are at high level, the design must ensure these are placed in low-pressure regions so that the wind reinforces rather than counteracts the stack effect.

Night ventilation

Night ventilation takes advantage of lower night-time temperatures to flush heat out of the building and pre-cool the structure. Reduced radiant temperatures enhance daytime comfort in warm weather. Proper consideration must be given to security issues when designing for night ventilation.

Mixed mode systems

Mixed mode systems deliberately combine natural and mechanical systems for ventilation and cooling. Such an approach can maximise both energy efficiency and occupant comfort. This requires the occupants and the building manager to understand the intentions of the design and how to operate the change-over controls.

Contingency planning can also allow naturally ventilated space to be quickly upgraded with appropriate mechanical systems.

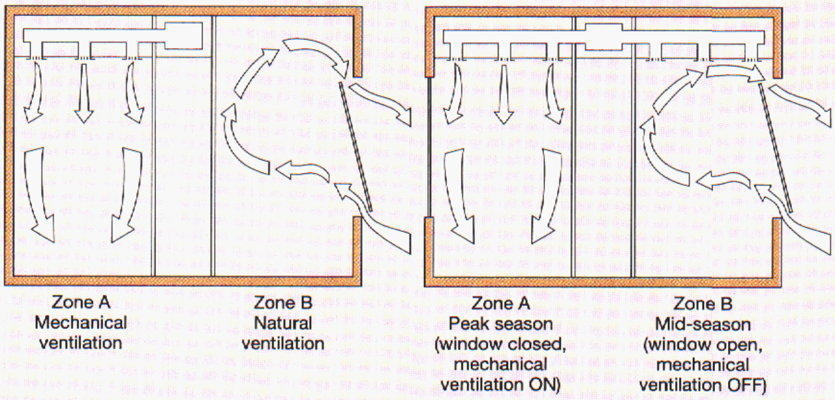
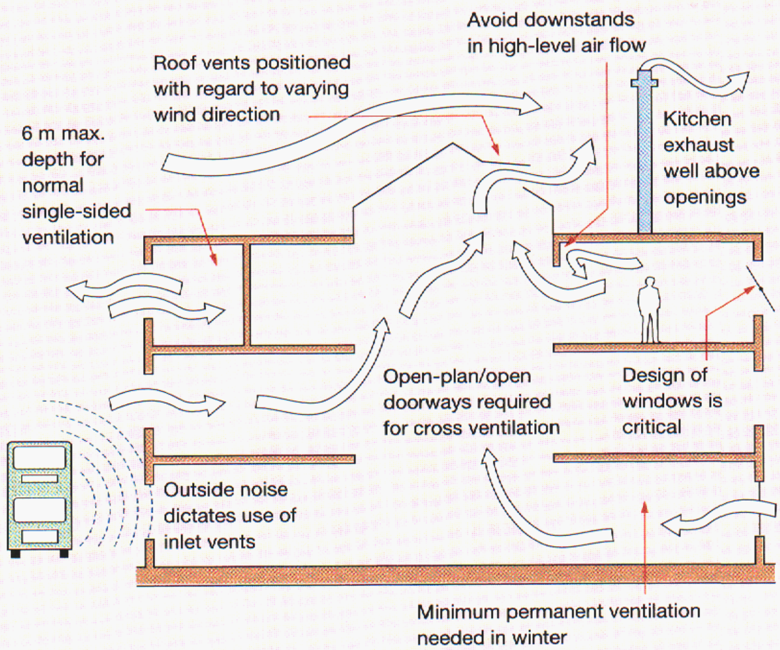


Figure 11 Mixed mode strategies (CIBSE Applications Manual 10, p5)

DESIGN STRATEGIES

Figure 12 Designing a flowpath – Anglia Polytechnic University (CIBSE Applications Manual 10, p24)



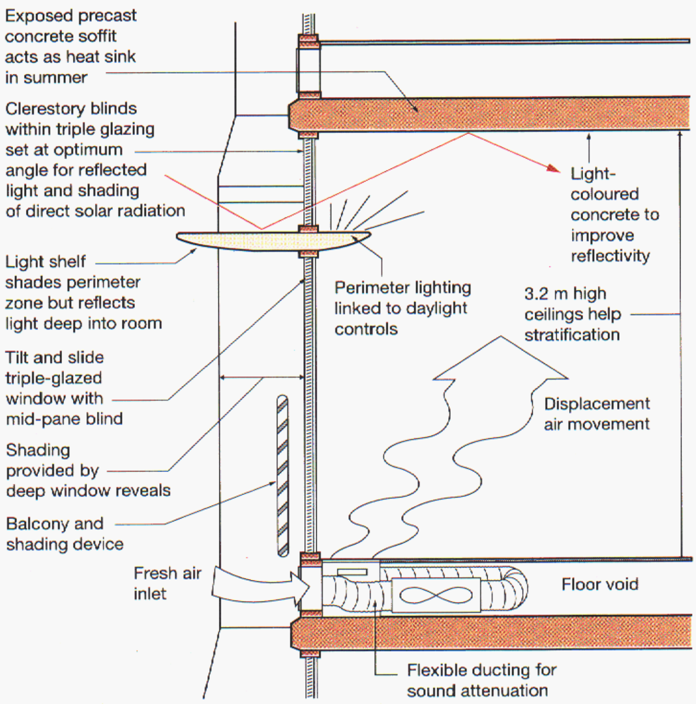


Figure 13 Façade detail – Inland Revenue Building (CIBSE Applications Manual 10, p46)

Design for natural ventilation

The key to successful design is to use an integrated design approach, regarding the design of the building form and fabric, and the heating, ventilation and air-conditioning systems as a single process.

The eight stages in the design process are as follows.

1. Agree the design brief, with special attention to likely heat loads and the required future flexibility of the building. Assess the effects of business culture (eg dress code) on temperature requirements.
2. Plan the flow path through the building for all operational regimes – summer, winter, mid-season, day and night (if night cooling is part of the strategy). Consider the sources of fresh air and the effects of any pollution sources (eg busy roads).
3. Identify any processes that might require special treatment (eg high heat gain or production of pollutants). If possible, group them together and consider treating the group separately (eg with mechanical extract).
4. Determine the ventilation rates required to satisfy air quality and thermal comfort requirements. This may involve several iterations in the detailing of the façade to control solar gains.
5. Estimate the driving pressures appropriate to the design

DESIGN STRATEGIES

Photograph: Bennets Associates/VIEW

Figure 14 Internal view of office area – Powergen Building

condition. This will be influenced by the climate, the geometry and layout of the building form as well as the surrounding terrain.

6. Select the ventilation devices (trickle vents, windows, louvres etc). Ensure that the rest of the building is constructed to appropriate standards of airtightness[10].

7. Use the design procedures listed in Chapter 5 of the CIBSE Applications Manual to size these openings. For properly engineered natural ventilation strategies, a high level of design analysis is needed and the effort required should not be underestimated.

8. Check the robustness and practicality of the design. For example:
- what is the velocity of the air through the openings and the implications for draught risk
- how sensitive is the design to operational misuse (eg if internal doors are closed in a cross flow strategy)
- is there a conflict with any other element of the design (smoke control, daylighting, security, etc)
- can the users easily get to the windows to adjust the opening size and hence the ventilation rate or do furniture layouts, internal columns etc restrict access
- can the needs of users deeper into the occupied space be satisfied as well as those who sit at the perimeter?

CASE STUDIES

Typical design issues

This section draws on a number of case studies which illustrate the design principles necessary in a naturally ventilated building. These are not unique examples; over 20 projects are described in the CIBSE Applications Manual[1], which contains more detail on the projects described here. The case studies in the manual cover commercial, educational and industrial buildings; they include low-rise and high-rise, greenfield and urban applications. These examples demonstrate that natural ventilation can play a role in a wide variety of building types in a range of different locations.

Case Study 1

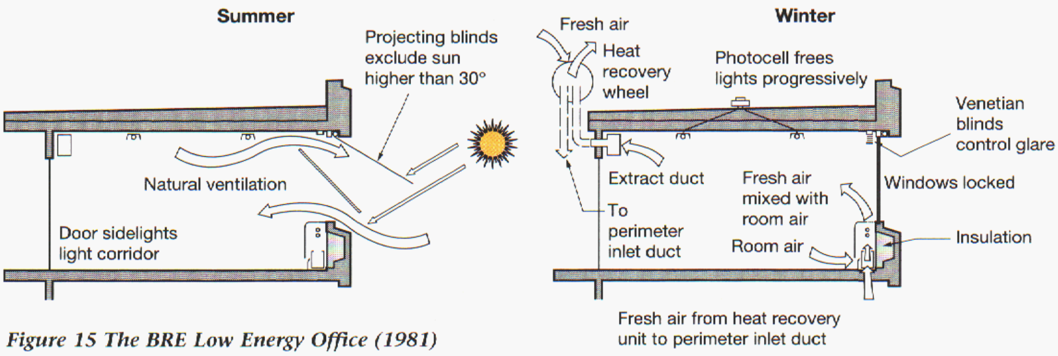
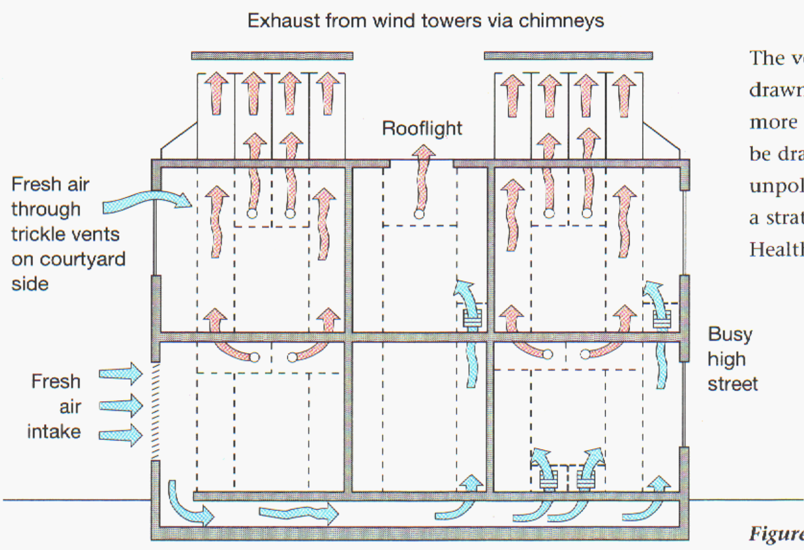


Figure 15 The BRE Low Energy Office (1981) (CIBSE Applications Manual 10, p72)

As well as planning the general flow strategy, the designer must give attention to local flow arrangements. Avoiding winter draughts as well as achieving cooling in summer must be considered. A strategy using mechanical ventilation during extreme weather conditions may be appropriate. Such an approach was used in the BRE Low Energy Office (built 1981), although the original means of heat recovery was replaced.

Case Study 2



The ventilation strategy must ensure that the air drawn into the building is not polluted. Although more problematic in city centre locations, air can be drawn through the building from a quiet, unpolluted side to exhaust on the street side. Such a strategy was used for the Canning Crescent Health Centre.

Figure 16 Canning Crescent Health Centre

CASE STUDIES

Case Study 3

Robust design requires the ventilation system to work under a range of weather conditions. The Ionica building uses wind towers to drive the natural ventilation. Depending on wind direction, different doors open on windward and leeward sides of the chimney. This wind-driven flow across the top of the chimney creates suction, drawing air from the atrium. The chimneys are arranged on a curved plan to avoid creating a wind shadow when the wind is along the building axis.

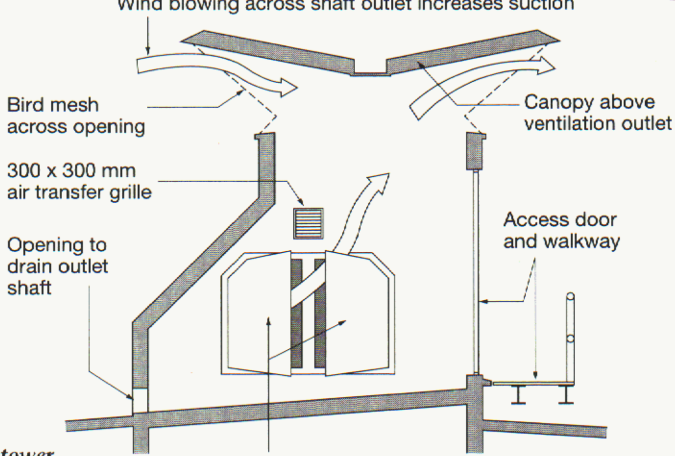


Figure 17 Section through the Ionica Building wind tower (CIBSE Applications Manual 10, p29)

Case Study 4

By exposing areas of internal brickwork or concrete ceilings, the increased thermal capacity of the space dampens out fluctuations in internal temperature. When coupled with night ventilation, acceptable internal comfort can be maintained, even during hot weather.

The cooling capacity of night ventilation can be three or four times greater than when ventilating during the daytime, because of the diurnal temperature swing. Night ventilation typically reduces peak daytime temperatures by 2°C-3°C in high thermal capacity buildings.

In the auditorium of the Queens Building, this approach is combined with temperature stratification. This allows hot air to collect above the occupied zone and to be exhausted via natural ventilation through stacks.

Photograph: Peter Cook/VIEW

Figure 18 De Montfort University auditorium (see New Practice Final Report 102 (NPFR 102) 'The Queens Building, De Montfort University – feedback for designers and clients')

CASE STUDIES

Integration with other design issues

The following two examples demonstrate how requirements for natural ventilation have been integrated with other design issues.

Case Study 5

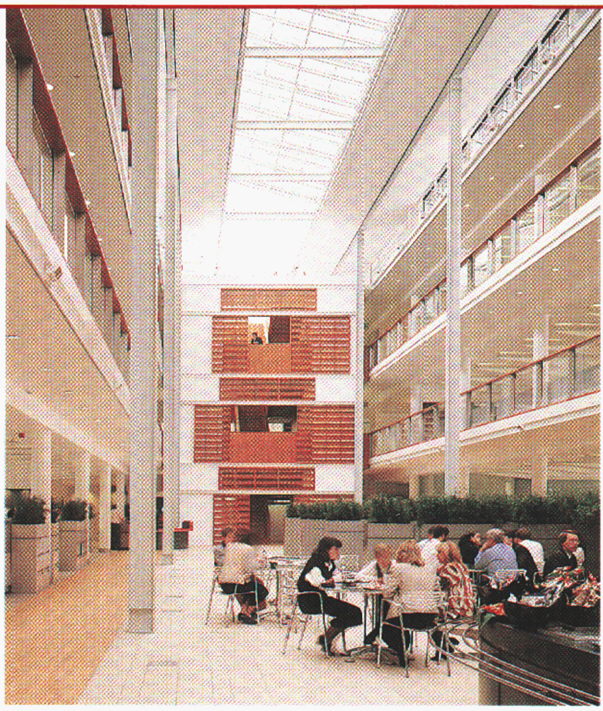
Photograph: Dennis Gilbert/VIEW

Acoustics

In the Inland Revenue Building, the ceiling is exposed to provide the required thermal inertia. This creates large areas of hard surface which must be treated to avoid acoustic problems. By using a wave-form soffit, the designers created visual interest as well as avoiding acoustic 'hot spots' by focusing the reflected sound below the floor level.

Figure 19 Inland Revenue Building – concrete soffit

Case Study 6



Photograph: Bennets Associates/VIEW

Space planning

The layout of the building must support communication within and between departments. In the Powergen building, this resulted in a narrow floor plan which is ideally suited to natural ventilation and daylight. The planning also led to the development of service centres providing photocopiers, coffee machines, etc. As well as promoting social contact, these service centres allow pieces of equipment which produce a lot of heat to be grouped together where the heat is extracted locally.

Figure 20 Powergen atrium and office areas

REFERENCE AND FURTHER READING

REFERENCES

[1] **Chartered Institution of Building Services Engineers**, Natural ventilation in non-domestic buildings, Applications Manual 10. CIBSE, London, 1997

[2] **Gardiner & Theobold**, Plan shape and building costs, Architect's Journal, 8 September 1994.

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[4] **Richard Ellis**, The British office market – the workplace of tomorrow; the consumer's view. London, 1994

[5] **Raw GJ, Roys MS and Leaman AJ**, Further findings from the office environment survey, Proceedings of the 5th International Conference on Indoor Air Quality and Climate. CHMC, Toronto, 1990

[6] **Leaman AJ, Cohen RR and Jackman PJ**, Ventilation of office buildings – deciding the appropriate system. Proceedings of the CIBSE National Conference, 1994 (Vol 2)

[7] **Department of the Environment, Transport and the Regions**, Energy efficiency in offices – small power loads, Energy Consumption Guide 35. DETR, London, 1993

[8] **Department of the Environment, Transport and the Regions**, A performance specification for the Energy Efficient Office of the Future, General Information Report 30. DETR, London, 1995

[9] **British Cement Association**, Project Profile, 1996. On behalf of the Reinforced Concrete Council

[10] **Building Research Establishment**, Minimising air infiltration in office buildings, BR265. BRE, Garston, 1994

FURTHER READING

BRE

BRE Digest 399, 'Natural ventilation in non-domestic buildings'. BRE, Garston, October 1994.

British Standards Institution

'Code of practice for ventilation principles and designing for natural ventilation'. BS 5925. BSI, London, 1991 (confirmed 1995)

DETR ENERGY EFFICIENCY BEST PRACTICE PROGRAMME DOCUMENTS

The following Energy Efficiency Best Practice programme publications are available from BRECSU Enquiries Bureau (contact details on the back page).

General Information Report

30 A performance specification for the Energy Efficient Office of the Future

31 Avoiding or minimising the use of air-conditioning – A research report from the EnREI Programme

48 Passive refurbishment at the Open University. Achieving staff comfort through improved natural ventilation

Good Practice Case Studies

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308 Naturally comfortable offices – a refurbishment project

334 The benefits of including energy efficiency early in the design stage – Anglia Polytechnic University

New Practice Final Report

102 The Queens Building, De Montfort University – feedback for designers and clients

106 The Elizabeth Fry Building, University of East Anglia – feedback for designers and clients

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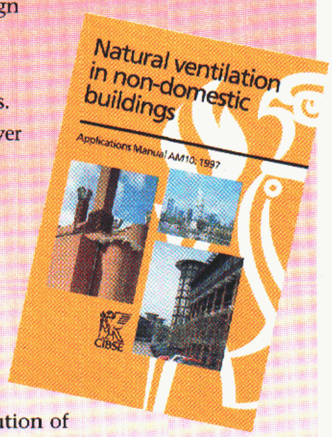

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General Information: describes concepts and approaches yet to be established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Introduction to Energy Efficiency: helps new energy managers understand the use and costs of heating, lighting etc.